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# Biomechanical reactions due to orthodontic forces. A finite element study

Cristina Bica[a,]*, Ligia Brezeanu[b], Dorin Bica[b], Mircea Suciu[b]

[a]*University of Medicine and Pharmacy, 38 Gh. Marinescu str, Tirgu-Mures 540000, Romania*
[b]*"Petru Maior" University of Tirgu Mures, 1 Nicolae Iorga, Tirgu-Mures 540088, Romania*

**Abstract**

The evaluation of biomechanical responses (displacements, stress) during the application of orthodontic_forces in adult patients with alveolar bone resorption can be achieved through the implementation of computer-assisted biomechanical processes and phenomena. The purpose of this study was to quantify, using Finite Element Method (FEM), the biomechanical reactions with two components, displacements and stress, following the application of orthodontic pressure in the presence of a periodontal support with a gradual loss of the alveolar bone. ALGOR V16 software allowed us to achieve simulations with horizontal forces of progressively increasing intensity over the middle point of the vestibular side of the tooth. The effect of the forces was assessed by the values of stress and displacements on the alveolar bone. For the correct interpretation of the results, we traced the features of stress on both, oral and labial sides.

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*Keywords:* Finite Element Method; Biomechanical reactions; Orthodontic force

## 1. Introduction

Orthodontics plays an important role in achieving a stable functional occlusion. The number of adult patients seeking orthodontic treatment is growing, and among them are cases of periodontal disease of variable severity which react differently to the application of orthodontic pressure than the patients with a healthy periodontal

* Corresponding author. Tel.: +40-723-180-682.
*E-mail address:*cristina.ioana.bica@gmail.com


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support. In an attempt to better understand the biomechanics of orthodontic tooth movement, a number of methods were used to "predict" tissue reactions caused by orthodontic pressure, such as: photo-elastic analysis, experimental animal studies, mathematical models, laser holography and the Finite Element Method (FEM).

FEM has been successfully used for several years in engineering and it uses the computer in solving certain systems with a large number of equations, in orders to determine the tensions and the displacements on the basis of the physical properties of analyzed structures [1, 2]. In orthodontics, the most important advantage of FEM is represented by the ability of including the heterogeneity of the dental-periodontal structures and the irregularity of the dental contour in designing of tooth.

Likewise, in order to have a competent and rigorous analysis, the FEM allows the application of pressure in different directions and with different intensities at any spot of the developed model.

In the dental field, FEM is used to investigate a number of problems related to tooth structure, biomaterials and restorative materials, dental implants and root canals [3-5].

The **purpose** of this paper is represented by the evaluation of the biomechanical reactions, stress and displacements, after applying horizontal forces on the teeth with different levels of alveolar bone loss.

## 2. Material and method

Comparative studies concerning the values of stress and displacements, after applying horizontal forces on the teeth with different levels of alveolar bone loss, have been carried out.

Three of three-dimensional models were created for the upper central incisor; these were adapted to the gradual reduction of alveolar bone. The simulated cases correspond to clinical situations with an alveolar bone reduction of 0, 2 and 4 mm (Fig. 1). The three-dimensional models developed are identical, with the exception of the height of the alveolar bone, which generates different geometric configurations.

The modelling the upper central incisor, with the help of the ALGOR finite element analysis program and design, was accomplished through the modification and the construction of the tooth, of the periodontal space, and of the surrounding alveolar bone according to dimensions and morphological data from specialized textbooks. Thus it was also taken into account the tilt of the tooth axis by 5 degrees, and, within the vertical plane of the tooth, some horizontal planes were created by modelling, at a level of the three elements of structure (tooth, periodontal ligament, alveolar bone) corresponding to the resorption degree of the alveolar bone [6-10].

Finite three-dimensional tetrahedral or bolt elements were used. The boundary conditions imposed on all peripheral nodes of the alveolar bone are conditions of null displacements. Between nodes of the elements composing the tooth - periodontal ligament - alveolar bone aggregate there were connections made through gap - type contact elements. The loading of the model was done through nodal forces, of various amplitude and directions depending on the phenomenon studied [2, 11-18].

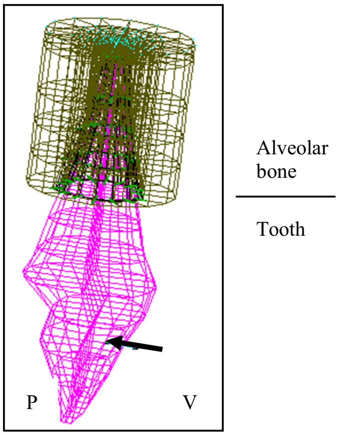


Fig. 1. Resorption of the alveolar bone

All materials of the FEM model (the coefficient of Poisson's ratio and Young's models) were considered elastic (Hooke's law validity) and isotropic (the same elastic properties in all directions).

We analyzed tooth movement and stress distribution following applications of some orthodontic forces of known intensity on the upper central incisor: horizontal orthodontic pressure that produces a tilting-type displacement, applied directly on the centre node in the vestibular forefront of the upper central incisor with various intensities F = 1 N - 3N - 5N, for the development of comparative studies of the results (assuming F = 1N as optimal orthodontic force, i.e. F = 5N as a supraliminal force).

## 3. Results

Comparative studies concerning the values of stress and displacements, after applying horizontal forces on the teeth with different levels of alveolar bone loss, have been carried out.

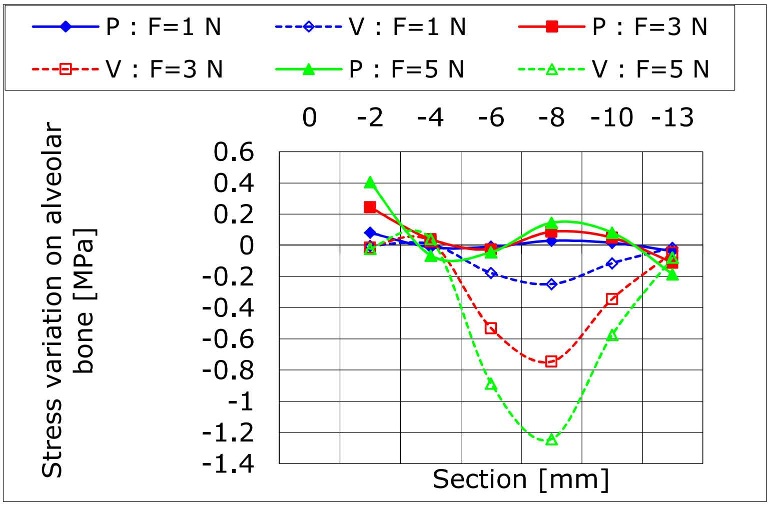


Fig. 2. Comparison: the variation of stress in the alveolar bone at different levels of force; resorption -2 mm

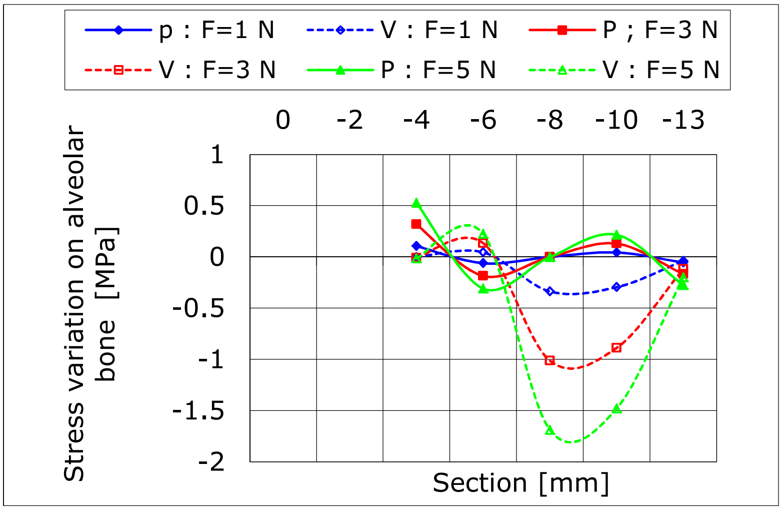


Fig. 3. Comparison: the variation of stress in the alveolar bone at different levels of force; resorption -4 mm

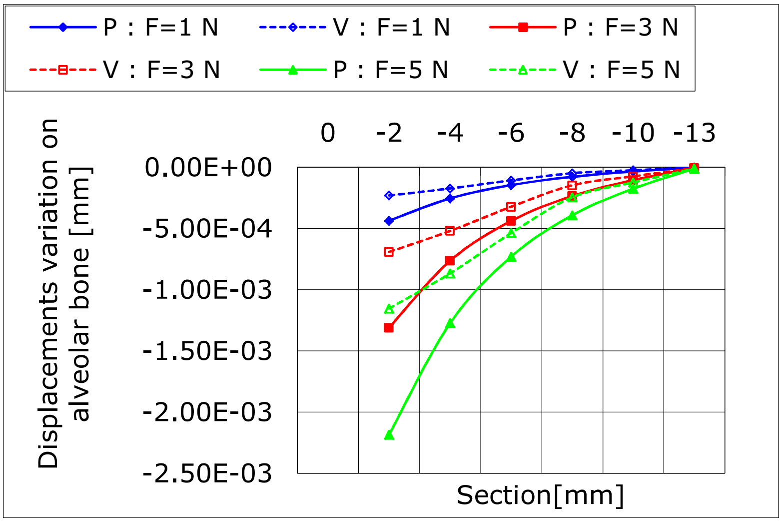


Fig. 4. Comparison: shifting in the alveolar bone for different force values; resorption -2 mm

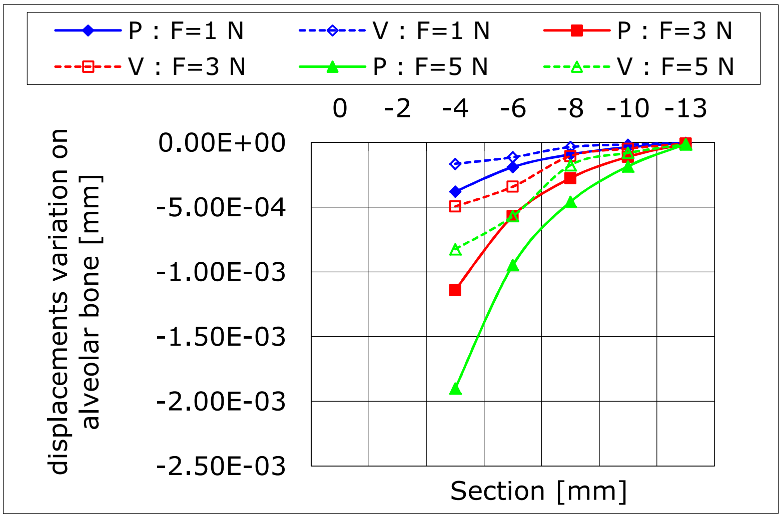


Fig. 5. Comparison: shifting in the alveolar bone for different force values; resorption -4 mm

### *3.1. Stress variation in the alveolar bone*

Regardless of orthodontic force value and horizontal resorption and regardless of size of the resorption, we have revealed at the cervical level the positive stretch-type values observed on the palatinal face (P), and much lower compression-type negative values observed on the vestibular face (V). There is a sharp increase in compression-type negative values on the vestibular side (V) towards the apex of the tooth, and much lower positive stretch-type values on the palatal side (P). The values of stress decrease at the apex level, but they become negative on both sides: palatal (P) and vestibular (V) (Table 1).

Comparing the variation of stress in the alveolar bone for a tooth without resorption with a stress variation in bone for a tooth with resorption, regardless of the degree of resorption, we have found that stress values are much higher in the tooth with resorption (Table 1, Fig. 2, Fig. 3).

### *3.2. Variation of movements in the alveolar bone*

We have found that similar phenomenon occur both for the tooth without resorption as for the tooth with resorption, irrespective of the value of tipping orthodontic force/pressure (Table 1, Fig. 4, Fig. 5). The shifting movements are wider at the level of the mass with the gradual decrease towards the apex. In all cases the shifting values are higher in the palatal face (P) than the vestibular side (V).

Shift values increase with the increase of the tipping orthodontic force. Shift values increase in the tooth with resorption compared to the tooth without resorption, as the resorption level is increased.

Table 1. Stress and displacements distribution on alveolar bone

| Force | Resorption | Maximum values of compression stress at the apical level | Maximum values of the displacements at the cervical level | |
|---|---|---|---|---|
| | | | Palatinal side (P) | Vestibular side (V) |
| F=1N | 0 mm | -0,10090 N/mm² | $5,06.10^{-4}$ mm | $2,97.10^{-4}$ mm |
| | -2 mm | -0,24845 N/mm² | $4,37.10^{-4}$ mm | $2,30.10^{-4}$ mm |
| | -4 mm | -0,33774 N/mm² | $3,80\ .10^{-4}$ mm | $1,64.10^{-4}$ mm |
| F=3N | 0 mm | -0,73654 N/mm² | $1,51.10^{-3}$ mm | $8,93.10^{-4}$ mm |
| | -2 mm | -0,74534 N/mm² | $1,31.10^{-3}$ mm | $6,92.10^{-4}$ mm |
| | -4 mm | -1,01324 N/mm² | $1,14.10^{-3}$ mm | $4,94.10^{-4}$ mm |
| F=5N | 0 mm | -1,26091 N/mm² | $2,53.10^{-3}$ mm | $1,48.10^{-3}$ mm |
| | -2 mm | -1,24224 N/mm² | $2,18.10^{-3}$ mm | $1.15.10^{-3}$ mm |
| | -4 mm | -1,68873 N/mm² | $1,90.10^{-3}$ mm | $8,23.10^{-4}$ mm |

## 4. Conclusions

The analysis of the results regarding the displacements and tensions in three-dimensional space stated that the relevant values are those which correspond to the direction of force's action.

The results obtained after computer simulation using the Finite Element Method, emphasize the displacements distribution on the tooth-periodontal ligament-alveolar bone ensemble. Alveolar bone loss leads to an increase of the orthodontic displacement values.

The stress depending on the force direction increases gradually with alveolar bone loss, both on the apical and cervical level. The loss of alveolar bone lowers the centre of tooth resistance and modifies the stress distribution at the apex.

The values of stress and displacements increase progressively along with the intensity of the applied force and with the degree of alveolar bone resorption.

Comparing the biomechanical reactions in the studied simulation cases, we noticed the intensification of the phenomena that occur in the presence of alveolar bone resorption.

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